

# **ALL-FIBER BROADBAND POLARIZATION COMBINER**

## **FIELD OF THE INVENTION**

This invention relates to an all-fiber polarization combiner for broadband applications. In particular, it relates to a Mach-Zehnder (MZ) structure in which the front  
5 coupler which is a polarization pump combiner (PPC) is made into a broadband combiner by controlling the phase between the two arms of the central zone of the MZ.

## **BACKGROUND OF THE INVENTION**

In applicant's Canadian Patent Application No. 2,354,903 and corresponding U.S. Patent Application No. 10/039,571 published under No. US 2003/0031415 A1 and  
10 incorporated herein by reference, there is disclosed a polarization combining fused-fiber optical coupler which is operational in a broad wavelength bandwidth, i.e. as a broadband coupler. It is made of two polarization maintaining (PM) fibers spliced to two standard single mode (SM) fibers which extend and are fused and drawn to make a coupling zone. In this arrangement, the linearly polarized light is injected into the PM  
15 fibers and oriented so that the polarization in one of the PM fibers is orthogonal to that of the other PM fiber, and when this light passes through the input arms of the SM fibers (the axes of which are aligned with the birefringent axes of the PM fibers) and into the coupling zone, the two polarizations are combined in this zone and emerge from one output fiber of the coupler with only a minimal power transmission going to the second  
20 output fiber.

Furthermore, a polarization selective phase shifting, splitting and combining optical device based on a Mach-Zehnder structure is disclosed in applicant's Canadian Patent Application No. 2,357,991 and corresponding US Patent Application No.  
10/090,128 published under No. US 2003/0063834 A1. In this MZ structure, a relatively  
25 small phase shift is produced, typically of one  $\pi$ , by splicing in one of the arms of the

central zone a segment of a PM fiber. A broadband polarization splitter or combiner may thus be achieved with a Mach-Zehnder structure where in the central zone, between the two couplers, a segment of a PM fiber is spliced in one of the arms to provide the required phase shifting. This is also described, for instance, in applicant's Canadian Patent Application No. 2,357,955 and corresponding U.S. Patent Application No. 10/045,190 published under No. US 2003/0063833 A1 with reference to Fig. 3 embodiment. This prior patent application also makes reference to broadband WDM fused fiber couplers.

Another all-fiber depolarizer with a polarization combiner based on a Mach-Zehnder interferometer structure is disclosed in applicant's Canadian Patent Application No. 2,393,172 and corresponding U.S. Patent Application No. 10/397,672 which also mentions a PPC used in order to scramble pump polarization. When it is desired to achieve a broadband operation with the PPC, inverted WICs (wavelength independent couplers) are utilized therewith.

## SUMMARY OF THE INVENTION

It was surprisingly found that by providing a Mach-Zehnder structure where the entry coupler is a PPC and the exit coupler is a wavelength division multiplexer (WDM) and inducing the phase shift  $\Delta\phi$  of  $\pi$  between the two arms in the central zone between the two couplers, one obtains a broadband PPC when linearly polarized light is injected into the input arms of the PPC coupler from PM fibers spliced to said arms and oriented so that the polarization X of one PM fiber is orthogonal to the polarization Y of the other PM fiber. In this manner, the broadband effect is maintained throughout the system, leading to the combined polarizations X and Y exiting from one of the output arms of the WDM coupler and essentially no power transmission going to the second WDM output arm.

Thus, the all-fiber broadband polarization combiner of the present invention comprises two polarization maintaining (PM) fibers having input and output ends, and oriented so that polarization X in one of the PM fibers is orthogonal to polarization Y in the other PM fiber, said PM fibers being spliced by their output ends to the input arms of a polarization pump coupler (PPC) which is connected through a central zone to a WDM coupler which has the same spectral spacing as the PPC and is centered to the same wavelength, thereby forming a Mach-Zehnder (MZ) interferometer structure with the output arm of the WDM coupler forming the output arms of the MZ interferometer; the phase shift  $\Delta\phi$  between the two arms of the central zone being set to a value of  $\pi$ , whereby the PPC is imparted with a broadband polarization effect and when broadband power is injected into PM fibers having polarizations X and Y respectively, it exits in combined form X and Y from one output arm of the MZ interferometer while the other MZ arm essentially has no power transmission going through it. This is due to the fact that the two wavelength responses from the two couplers are subtracted from one another.

Thus, by providing a broadband PPC in this manner, use of inverter WICs is eliminated and the splicing of a PM fiber section in one of the arms of the central zone is avoided, thus removing the necessity to align the coupler arms with the PM fibers at the entry and reducing losses due to the splicing of the PM fiber section in the arm of the central zone. Consequently, considerable advantages are produced by this simple and efficient MZ polarization combining structure.

#### BRIEF DESCRIPTION OF THE DRAWINGS

A preferred embodiment of the present invention will now be described with reference to the appended drawings, in which:

Fig. 1 is a schematic representation of the all-fiber broadband polarization

combiner of the present invention;

Fig. 2 is a graph showing curves of PPC transmission and WDM coupler transmission, where transmission power in dB is plotted with reference to the wavelength in nm;

5 Fig. 3 is a graph showing curves of a spectral response of MZ structure of PPC and WDM coupler with a zero phase shift plotted in dB power with reference to the wavelength in nm.

Fig. 4 is a graph showing curves of a spectral response of MZ structure of PPC and WDM coupler with a phase shift of  $\pi$  plotted in dB power with reference to the  
10 wavelength in nm; and

Fig. 5 is a graph showing the response at the exit of the broadband polarization combiner of the present invention.

#### DETAILED DESCRIPTION OF THE INVENTION

The invention will now be described by way of a preferred, non-limitative  
15 embodiment, with reference to the appended drawings.

Fig. 1 schematically illustrates the novel all-fiber broadband polarization combiner 10 in which two PM fibers 11 and 12 are spliced at points 14 and 16 to standard SM fibers 18, 20. The PM fibers 11, 12 may, for example, be PANDA™ fibers and the SM fibers are preferably SMF-28 fibers of Corning because they are particularly  
20 suitable for splicing with low losses. The PM fibers 11, 12 are so oriented that when light is injected into them from a light source (not shown), it is transmitted with polarizations X and Y being orthogonal to each other. The light source(s) is normally broadband, emitting signals with several wavelengths.

The SM fibers 18, 20 form the input arms of PPC 22 which is made by fusing  
25 and elongating these fibers in known manner. The output arms 24 and 26 extend through

a central zone 28 and are again fused and elongated to form a WDM coupler 30 also in a known manner. The WDM coupler has the same spectral spacing as the PPC and is centered to the same wavelength. The output arms 32 and 34 of the WDM coupler also represent the output arms of the broadband polarization combiner 10.

5           The structure of the novel broadband polarization combiner 10 is that a Mach-Zehnder interferometer (MZ) and the broadband effect is achieved by setting the phase shift  $\Delta\phi$  in the central zone 28 to  $\pi$ . It should be noted that the phase shift need not be precisely  $\pi$  which in itself represents an indefinite number, but merely approximately  $\pi$  to achieve the desired broadband operation. This phase shift may be imparted by  
10       different means, such as changing the refractive index of one of the fibers in the central zone 28 by UV radiation or subjecting one of the fibers to mechanical stress, or the like. It was surprisingly found that when the  $\pi$  phase shift is induced into this MZ structure, the PPC 22 becomes a broadband PPC, thereby making the entire polarization combiner  
15       10 a broadband device. As already previously indicated, the broadband polarization combiner makes it possible to obtain a wide wavelength bandwidth greater than 8nm for an isolation at the outlet of 17 dB or greater.

          Fig. 2 shows the transmission curves of PPC and WDM couplers respectively. Curve A is the transmission of polarization X and curve B of polarization Y. There were actually spacings of 68nm and 75nm for the two orthogonal polarizations. The  
20       transmission of the WDM coupler is represented by curve C for the two output ports. No broadband polarization combining is obtained.

          Fig. 3 shows a graph of transmission achieved by the Mach-Zehnder structure shown in Fig. 1, but with zero phase shift. Again, curve A is the transmission of polarization Y, and curve C is the transmission of the WDM coupler. As is obvious from  
25       this graph, the responses of the couplers are added to one another in this case, and no

broadband polarization combining is obtained.

Fig. 4 shows a graph of a transmission achieved by the Mach-Zehnder structure shown in Fig. 1 where, in accordance with the present invention, the phase shift is  $\pi$ .

Curve A is the transmission of polarization X, curve B is the transmission of polarization

5 Y and curve C is the broadband transmission coming of the WDM coupler.

Finally, Fig. 5 shows the power transmission coming out of the two output ports of the novel all fiber broadband polarization combiner. Here, it is seen that curves A and B representing polarizations X and Y respectively exit from one output port of the device in a broadband combination, while at the other output port, the power transmission C is almost zero.

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The invention is not limited to the preferred embodiments described above and various modifications obvious to those skilled in the art can be made without departing from the scope of the following claims.